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A PRELIMINARY ANALYSIS OF KRAKATAU SEISMIC DATA DURING THE 1992/1993 ERUPTIONS

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ABSTRACT

During the period of Anak Krakatau activity (started on November 1992), measurements of seismicity using a single vertical 1 Hz seismometer has been carried out. The data are transmitted to the 60 km distant Carita Beach, West Java, where are recorded on analog form. We used ink paper recording and sample recording on magnetic tape. Additionally, the envelopes of seismograms are also digitally recorded.

To get more detailed seismic information about the source of activity, sporadic measurements at Anak Krakatau island have been carried out in the periods December 1992, May and August 1993, using a 5 second (semibroadband) 3 component seismometer (Le3D/5s). These measurements were also accompanied by visual observations, acoustic noise and video recordings.

In this paper we tried to analyze the pattern of eruptions. Through the use of phase space reconstruction, we examine the relation between eruption intervals. We conclude that the phase space portraits of Anak Krakatau eruptions, obtained by applying reconstructive techniques to shock interval data during the activity clearly illustrate the deterministic chaotic nature of the system.

A simple conceptual model of volcanic eruption behaviour was also presented. In order to approach the source time function of eruption, we tried to restitute the signals to reduce response of the instrument. As the seismograms were recorded on a site of less than 1 km distance to the source, the station is still in the near field. Therefore, the restituted ground displacement seismogram approaches the source time function (wavelet), at least in the initial phase.

I. INTRODUCTION

I.1. Nature of Eruptions

The entire cone of Anak Krakatau island has been built up of pyroclastic material and lava flow, and the 1992/1993 eruptions were no exception. Explosive eruptions occurred at 20 seconds to 10 minutes interval. The peak of activity took place during the period of November and December 1992.

The activities were marked by almost regular repetition of explosions, and rapidly rising turbulent mushroom black smoke reached 1000 meters height. The eject range from fine ash to 2 meters angular blocks of incandescent andesitic-basaltic lava. The blocks are thrown beyond the outer crater rim to a maximum of 1 km horizontally from the vent during the larger explosions. The noise of explosions corresponding to the extruded materials (pyroclastic and gas jet) was very impressive, but the sounding was deep and almost noiseless when the turbulent explosion clouds grew upward. This situation was different from the 1960 eruptions, where the noise of the explosions even with the largest was not impressive (Decker and Hadikusumo, 1961).

The flowing lava scattered to the north-east direction at the beginning, and then moved to the South and west covering the coast in those directions. The point of eruption was located on the north-east part of the old crater, and formed a new crater with about 100 m diameter. The eruption activities decreased in the beginning of February, and in May 1993 the eruptions practically occurred at one to two hours' intervals. The 1992/1993 eruptions perhaps were the best described of Strombolian type.

I.2. Seismic Measurements

A permanent seismic station was installed at the southern part of Anak Krakatau Island (6° 6' S and 105° 25' E). The station is located on the 50 m altitude and about 500 m distant to the crater region. It consists of a single vertical component 1 Hz transducer that records ground velocity, and radio telemetric system. The data are received at the 60 km distant Carita Beach, West Java, and recorded on ink paper and magnetic tape (DAT) in analog form.

In the middle of January 1993, the station was covered by lava flow and destroyed. A new station was built up located at the eastern part of the Island near the coast. However ten days later, the telemetry system of the new station was broken by lava bombs. Upon this event, the transmitter was moved to the coast, and on May 1993, we built a new station not so far from the last one.

Parallel with the analog recordings, the envelope of seismograms was also recorded digitally by using a Tattle Tale data logger manufactured by Onset Company. The data are sampled with 2 seconds sampling interval and recorded continuously to HD of a Laptop PC. Twenty five days of continuous envelope data were obtained.

A three component Lennartz semibroadband (5 second) seismometer was deployed for one day in May 6 and August 14, 1993, at Anak Krakatau Island. The purpose was to find out if the volcanic seismic events contain energy at lower frequencies than that could be recorded by the traditionally short period seismometers with typically 1 Hz eigenfrequency. Horizontal components are also important to explain the possible source mechanism of the eruption.

The instruments were set up at three locations, with azimuths N75° E, N88° E, N100° E with respect to the crater region. The horizontal distance to the crater was about 600 m, 30 m above sea-level. The orientation of the transducer was practically in such away that the N-S direction as the transverse component and the E-W direction as the radial component in respect to the crater area. For data acquisition we used MARS 88 manufactured by Lennartz Company. The 3 component signals were recorded with sampling interval 32 ms and dynamic range 96 dB (16 bit). The signals which is proportional to the ground velocity were recorded on floppy disk. About one hundred and fifty shocks were recorded during the measurements. A typical shock which has a clear and sharp onset of the first arrival was selected for deeper investigation in this paper.

II. DATA ANALYSIS AND INTERPRETATION

II.1. Short-period Data

Seismic data from ink paper recorded by VSI (Volcanological Survey of Indonesia) show that the signals during the 1988 eruptions were dominated by perfectly harmonic tremor, that is a monochromatic sinusoid waveform with dominant frequency 1.6 Hz (see Fig. 1). We believe that the harmonic character of the tremor is due to the source effect, namely the resonant vibration of magma body.

The 1992/1993 eruptions are of Strombolian type, which have almost regular repetitions of the explosions, high gas content and pressure with the turbulent black smoke. From the video recording we found out that the signal amplitudes have high correlation to the violence of the individual eruptions. Figure 2 shows an example of the envelope of seismograms recorded on December 25, 1992. From this figure we can see that the onsets of the shocks are very clear and sharp with practically without noise in the time between.

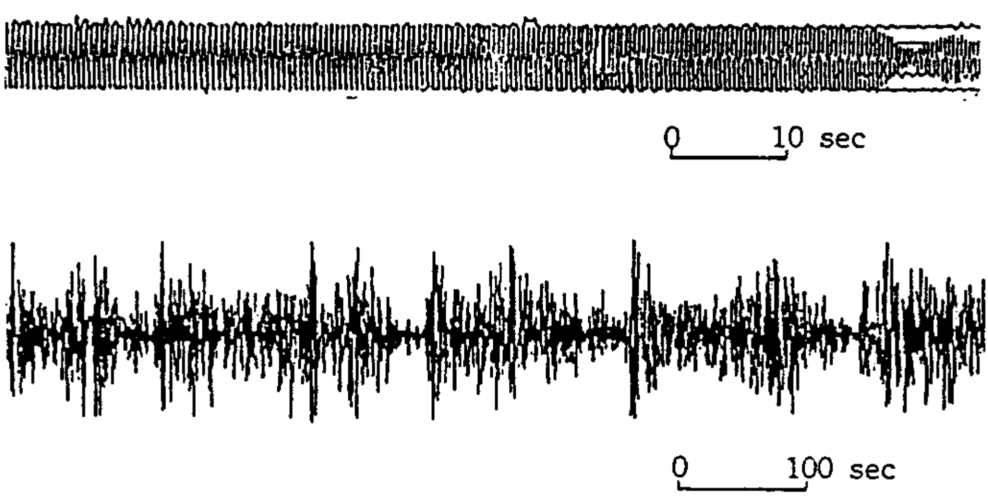

Fig. 1. Harmonic tremor of the 1988 Krakatau eruption (above), and seismic signals of the 1992 eruption (bottom).

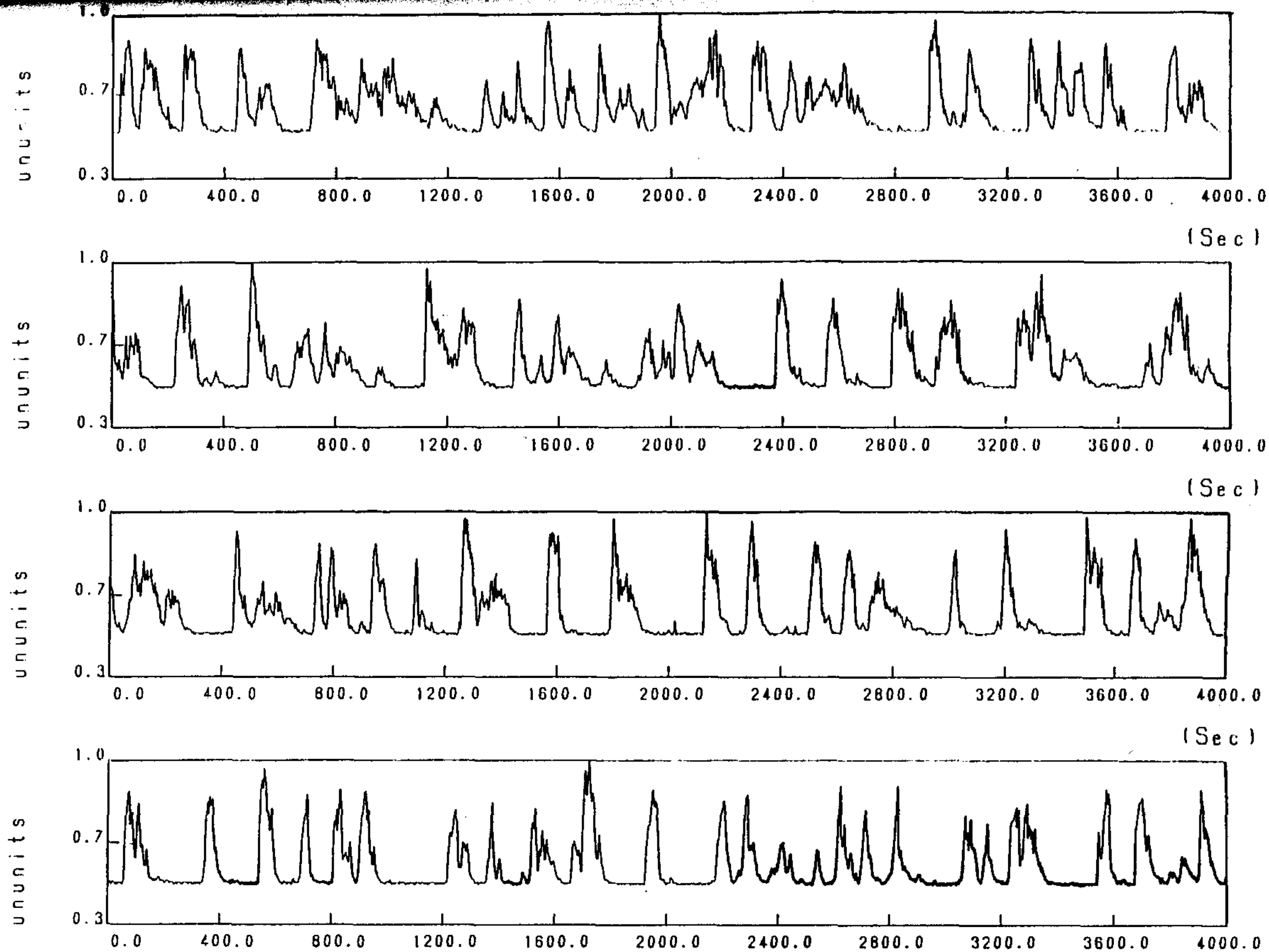

Fig.2. ABSOLUT WAVEFORM ENVELOPE (KRAKATAU, 21 NOV.1992)

II.2. Pattern of Eruptions

In general, the eruptive pattern of Anak Krakatau is complex and not regular. In the next analysis, we present an evidence that the sequence of eruptions of Anak Krakatau may display a deterministic chaos behavior. It is well known that deterministic chaos describes the behavior of certain dynamically systems which governed by deterministic laws, but displays an apparent stochastic output signal (Nicholl et al., 1994).

The phenomenon of deterministic chaos occurs when feedback from non linear coupling destroys information regarding the initial state of the system. The concept of deterministic chaos can be illustrated by observing the temporal evolution of a dynamically system in phase space. Phase space reconstruction is used to demonstrate the existence of a strange attractor. The attractor of a chaotic system should have a specific topological shape, displaying infinite complexity in a bounded structure. The principle is that successive events in a deterministic system are related, and therefore the structure of the attractor can be revealed through the interval or lag between these events.

Observable variables which affect the eruption behavior of Anak Krakatau might include : eruption intervals, event duration's, eruption heights, temperature patterns, etc. In this analysis eruption interval's data will be examined for signs of chaotic behavior. The data used in this study consists of 360 shock interval's data occurred during November 21-22, 1992, and 610 data for December 25-26, 1992. The data was taken from the seismogram envelope recordings.

A method of plotting various lags on different axes is applied to these data. Figure 3a represents a 2D phase space plot for the data mentioned above. The figure shows a specific pattern in which the points are distributed in a bounded structure. The point distributions look to be attracted to the bottom left direction, llustrating a specific structure of a strange attractor. To compare this structure, with the same method plot of points generated randomly about a mean is shown in figure 3b. The plots notify an almost unbounded structure in spherical distribution.

Through the use of phase space reconstruction, we can examine the relation between eruption intervals. The question is: Is that a current interval more closely related to the preceding interval than it is to one further in the past ? In order to answer this question, two dimensional plots were contracted with the current lag (T_n) on the X axis, and the previous intervals (T_{n-1}) on the Y axis. Figure 4 a, b, c, d, shows selected plots from this analysis ; (a) for T_n vs T_{n-1} ; (b) for T_n vs T_{n-2} ; (c) for T_n vs T_{n-3} ; and (d) for T_n vs Tn_{n-4} .

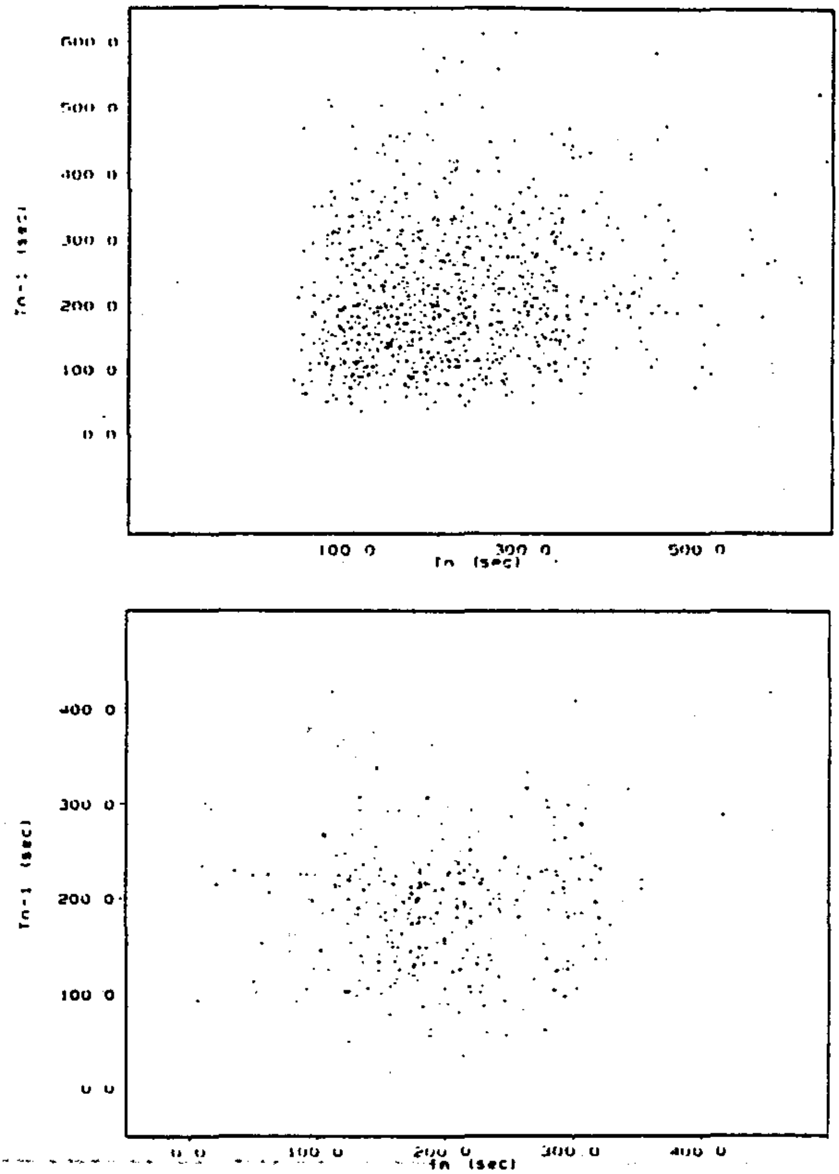

Fig. 3. Two-dimensional phase space plots of shock interval data, taken on November 21-22 and December 25-26, 1992. The interval associated with the current shock (Tn) is shown in the horizontal axis, and the interval associated with preceding shocks are shown in the vertical axis. Similar procedure for the random number (bottom).

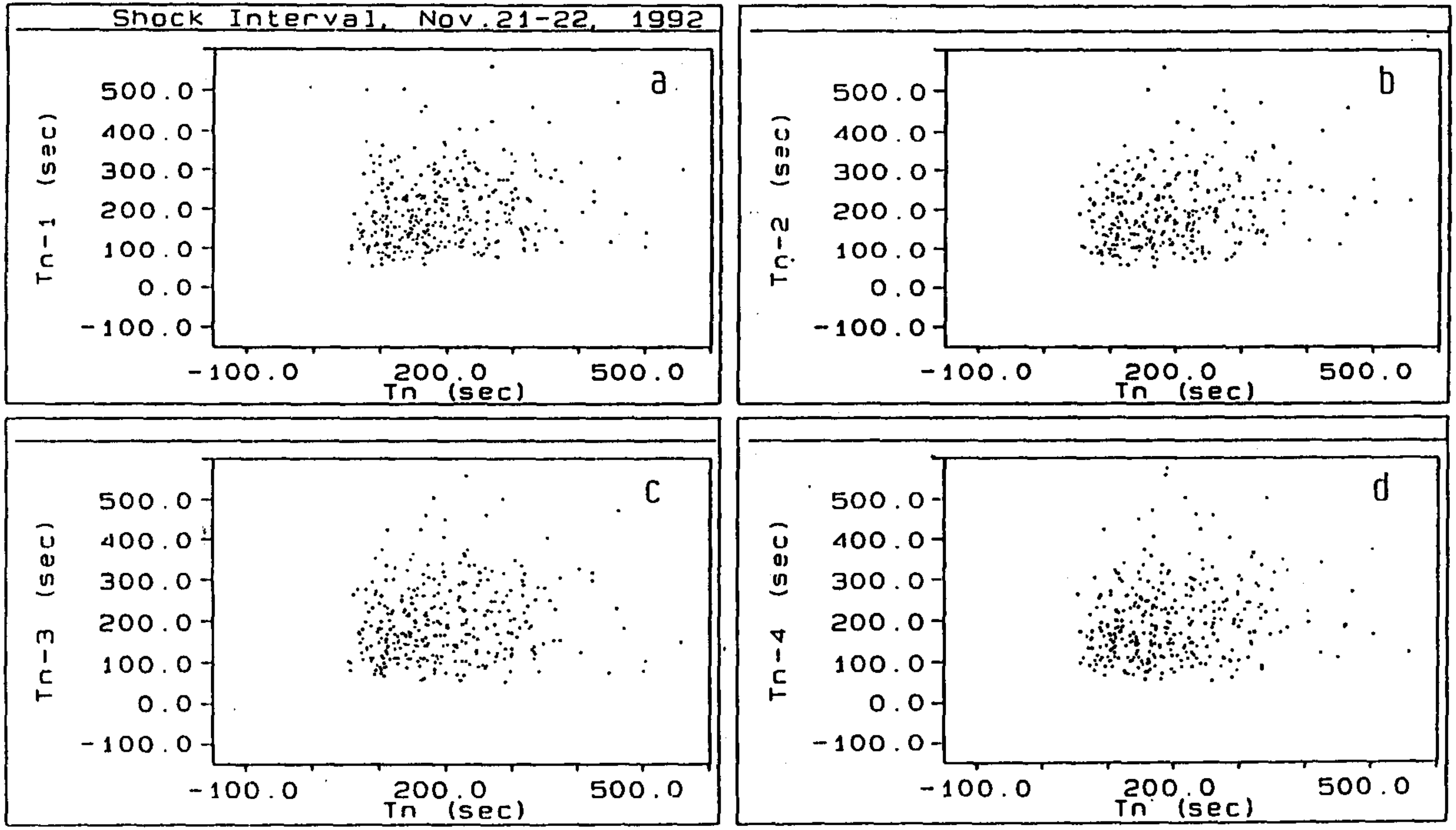

Fig.4. Two-dimensional phase space plots of shocks interval data for various lags, the data are

We can see that all of plots have similar structure in various lags, exhibiting that there is no loss of information during evolution of the system, indicating that there is no significant noise which obscures the attractor. We conclude that the phase space portraits of Anak Krakatau obtained by applying reconstructive techniques to the shock (eruption) intervals data during the activity clearly illustrate the deterministic chaotic nature of the system.

II.3. Model of Eruptions

The physical mechanism of Anak Krakatau eruptions is not well known. However, there is a well understood fact that the source of signal is connected with non steady flow of magma, two-phase flows (gas/vapor and liquid magma) (Schick, 1988). Numerous instabilities in two-phase flow may, with a proper feedback, lead to periodic flow and pressure pulsation. A major instability in fluid flow represents the transition from subsonic to supersonic flow and vice versa.

It is impossible to model the eruptive process of Anak Krakatau in a completely deterministic manner, because the system contains infinite degrees of freedom. However, a simple conceptual model that captures the essential dynamics of volcanic eruptions behavior might be as follows : (1) The eruptive cycle begins with the volcano at a minimum energy state. (2) The energy (heat and pressure of magma and gas) is injected from the deeper feeding conduit system to the shallower levels, expanding gas or steam pressure until a critical state is reached. (3) At a critical point, a quantity of mass (lava, gas, vapor) and heats are ejected through the conduit (feeding system), resulting seismic signals and explosions on surface (extruded lava and gas jets), the energy is released. (4) Process begins again (repeat as from point 1).

II.4. Simple Source Function

About one hundred and fifty shocks were collected during a one day measurement at Anak Krakatau on May 06, 1993. The measurement used a three component long-period seismometer that has 0.2 Hz eigenfrequency. In this paper, we refer on the analysis of a typical shock with a very clear and sharp onset of the arrival. Figure 5 shows the vertical, transversal, and radial component of Anak Krakatau ground velocity seismograms. The data are sampled by 32 ms interval.

In order to approach the source time function of eruptions, we tried to restitute the seismic signals to reduce the response of the instrument. It was done by applying an inverse filter of the instrument frequency response to the seismograms. The restituted seismograms were integrated to reveal ground displacement. As the seismograms were recorded on a site of less than 1 km distance to the source, the station is still in the near field. Therefore, the restituted ground displacement seismograms approach the source time function (wavelet), at least in the initial phase.

Figure 6 shows the zoomed displacement seismograms after restitution, the starting frequency is 0.01 Hz. From these figures we can see that the vertical component is more stable in shape and frequency, but the horizontal components especially the radial component, displays a significant low frequency. A very slow rising positive polarity in radial component (Fig. 6), means a ground motion away from the crater region, indicating an accumulating pressure or energy in the system. The following suddenly negative polarity showing a ground motion towards the crater region, indicating the pressure/energy release in the system. It is possibly caused by movement of fluid through a narrow section of the magma system.

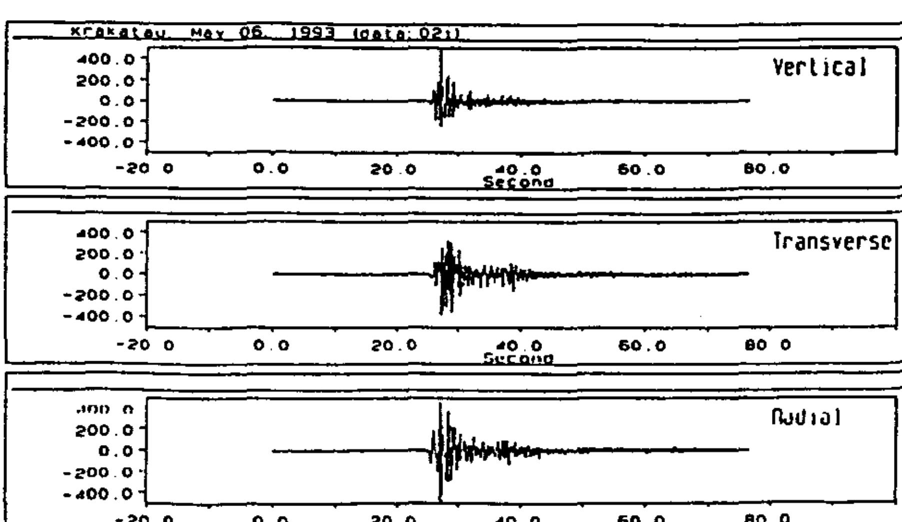

Fig. 5. Vertical, tranversal and radial components of the Anak Krakatau ground velocity seismograms, the data are sampled of periode 32 ms.

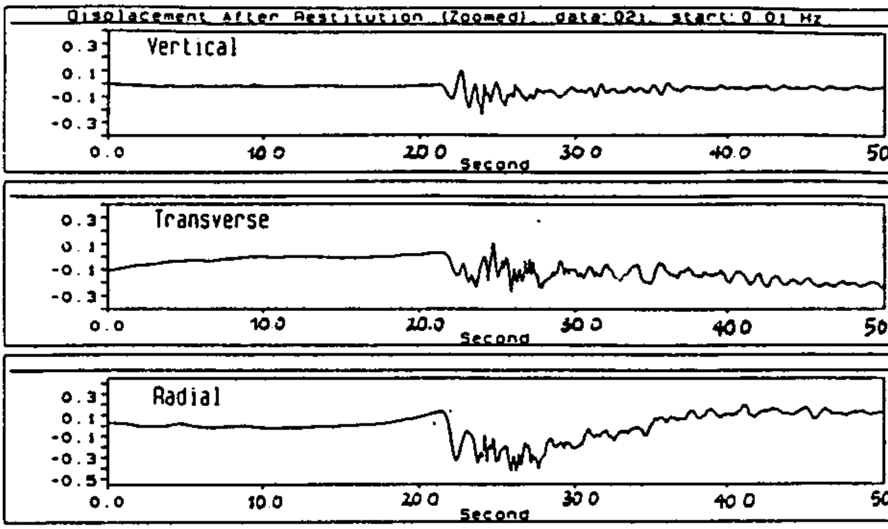

Fig.6. Zoomed displacement restituted seismograms, the starting frequency is 0.01 Hz.

III. CONCLUSIONS

The presented results indicate that the seismo-volcanic events on Anak Krakatau during the 1992/1993 eruptions are composed of signals that have different character than the signals from the 1988 eruption. The 1992/1993 eruptions might be the best described as Strombolian eruption, while the 1988 eruptions are more effusive.

The mean value of shock intervals counted from the envelope data is 200 seconds. There is no correlation to the diurnal or semidiurnal periodicities. The phase portraits of Anak Krakatau obtained by applying reconstructive techniques to eruption/ shock interval data during the activity illustrate the deterministic chaotic nature of the system. However, it is impossible to model the eruptive process in a completely deterministic manner.

A simple conceptual model of volcanic eruptions was presented. From the three component semibroadband (5 second) seismometer, we found a simple wavelet showing ground motion towards rather than away from the crater region, indicating a pressure/energy release caused by fluid movement through the narrow section of the magma system.

REFERENCE

Braun, T., M. Ripepe, 1993. *Interaction of Seismic and Air-waves recorded at Stromboli Volcano.* Geophysical Research Letter, Vol. 20,No.1,pp.65-68.

Decker, R.W., D. Hadikusumo, 1961. *Results of the 1960 Expedition to Krakatau.* Journal of Geophysical Research, Vol. 66, No. 10, pp. 3497-3511.

Harjono, H., M. Diament, L. Nouaili, J. Dubois, 1989. *Detection of Magma Bodies Beneath Krakatau Volcano (Indonesia) from Anomalous Shear Waves.* Journal of Volcanology and Geothermal Research , Vol. 39, pp. 335-348.

Moon, F.C., 1987. *Chaotic Vibrations, an Introduction for Applied Scientists and Engineers.* A Wiley-Interscience Publication, New York.

Neuberg, J., R. Luckett, M. Ripepe, T. Braun, 1994. *Highlights from a Seismic Broadband Array on Stromboli Volcano.* American Geophysical Union.

Nicholl, M.J., S.W. Wheatcraft, S.W. Tyler, B. Berkowitz, 1994. *Is Old Faithful a Strange Attractor ?* Journal of Geophysical Research, Vol. 99, No. B3, pp. 4495-4503.

Schick, R., 1988. *Volcanic Tremor, Seismic Signals of (almost) Unknown.* Paper presented at the IAVCEI. Capri-Italy.

Schick, R., W. Mueller, 1988. *Volcanic Activity and Eruption Sequences at Stromboli During 1983-1984. In Modeling of Volcanic Process.* Friedf. Vieweg & Sohn Verlagsgesellschaft GmbH, Braunschweig.